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Annual chronotypes functionally link life histories and life cycles in birds

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Abstract

© 2018 The Authors. Functional Ecology © 2018 British Ecological Society Life-history responses to ecological selection pressures can be described by a slow–fast life-history axis. Along this axis, fast-living animals usually invest in high breeding output, whereas slow-living ones prioritize their own survival. Birds may solve the trade-off between reproduction and survival by optimizing their seasonal schedules. Breeding early tends to facilitate reproductive success, whereas breeding late increases the chances to survive. On the basis of this argument, short- and long-lived birds should benefit from initiating spring activities earlier and later, respectively. The timing of seasonal activities, all else being equal, depends on the architecture of endogenous circannual clocks. Particularly, the length of the circannual period relative to the 365-day environmental year either facilitates the anticipation of seasonal activities (in case of periods shorter than 365 days) or represents a responsive mode (when periods are longer than 365 days). The two alternatives will be manifested by early or late annual chronotypes, respectively. We hypothesize that in birds, annual chronotype will correspond with position on the "pace-of-life scale." Species with low survival probability, and thus a poor chance of breeding in a next season, should show early annual chronotypes facilitated by circannual-clock periods shorter than 365 days. In contrast, species with high survival rates should benefit from relatively long circannual periods. We predicted that circannual-period lengths should correlate positively with species-specific adult annual survival rates. Using published data for 16 wild bird species, we confirmed the predicted correlation. In our analysis, we accounted for the possible metabolic nature of circannual clocks, a correlation between rate of metabolism and survival, and phylogenetic relationships. On the basis of our finding, we propose that evolutionary responsive circannual clocks help birds cope with temporal variation in the environment in ways that are most appropriate for their life-history and life-table attributes. A plain language summary is available for this article.

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Keywords

annual chronotype, circannual rhythm, life cycle stage, metabolic rate, pace-of-life, reproduction–survival trade-off, seasonal migration, slow–fast life-history continuum

References

[1] Akaike, H. (1974). A new look at the statistical model identification. IEEE Transactions on Automatic Control, 19, 716–723. https://doi.org/10.1109/TAC.1974.1100705

[2] Åkesson, S., Ilieva, M., Karagicheva, J., Rakhimberdiev, E., Tomotani, B., & Helm, B. (2017). Timing avian long-distance migration: From internal clock mechanisms to global flights. Philosophical Transactions of the Royal Society B, 372, 20160252. https://doi.org/10.1098/rstb.2016.0252

[3] Alonso, D., & Arizaga, J. (2013). The impact of vagrants on apparent survival estimation in a population of common crossbills (Loxia curvirostra). Journal of Ornithology, 154, 209–217. https://doi.org/10.1007/s10336-012-0887-2

[4] Battley, P. F., Dekinga, A., Dietz, M. W., Piersma, T., Tang, S., & Hulsman, K. (2001). Basal metabolic rate declines during long-distance migratory flight in great knots. Condor, 103, 838–845. https://doi.org/10.1650/0010-5422(2001)103[0838:BMRDDL]2.0.CO;2

[5] Bazzi, G., Cecere, J. G., Caprioli, M., Gatti, E., Gianfranceschi, L., Podofillini, S., … Rubolini, D. (2016). Clock gene polymorphism, migratory behaviour and geographic distribution: A comparative study of trans-Saharan migratory birds. Molecular Ecology, 25, 6077–6091. https://doi.org/10.1111/mec.13913 https://doi.org/10.1111/mec.13913

[6] Berthold, P. (1977). Über eine mögliche endogene Steuerung der Zugdisposition beim Fichtenkreuzschnabel Loxia curvivorstra. Journal of Ornithology, 118, 203–204. https://doi.org/doi/10.1007/BF01648323

[7] Berthold, P. (1982). Endogene Grundlagen der Jahresperiodik von Standvögeln und wenig ausgeprägten Zugvögeln. Journal of Ornithology, 123, 1–17. https://doi.org/10.1007/BF01644145

[8] Berthold, P., Gwinner, E., & Klein, H. (1972). Circannuale Periodik bei Grasmücken. I. Periodik des Körpergewichtes, der Mauser und der Nachtunruhe bei Sylvia atricapilla und S. borin unter verschiedenen konstanten Bedingungen. Journal of Ornithology, 113, 186–189

[9] Bielby, J., Mace, G. M., Bininda-Emonds, O. R. P., Cardillo, M., Gittleman, J. L., Jones, K. E., … Purvis, A. (2007). The fast-slow continuum in mammalian life history: An empirical reevaluation. American Naturalist, 169, 748–757. https://doi.org/10.1086/516847

[10] Bradshaw, W. E., & Holzapfel, C. M. (2007). Evolution of animal photoperiodism. Annual Review of Ecology, Evolution, and Systematics, 38, 1–25. https://doi.org/10.1146/annurev.ecolsys.37.091305.110115

[11] Bulla, M., Valcu, M., Dokter, A. M., Dondua, A. G., Kosztolányi, A., Rutten, A. L., … Kempenaers, B. (2016). Unexpected diversity in socially synchronized rhythms of shorebirds. Nature, 540, 109–113. https://doi.org/10.1038/nature20563 https://doi.org/10.1038/nature20563

[12] Chandola-Saklani, A., Thapliyal, A., Negi, K., Diyundi, S. C., & Choudhary, B. (2004). Daily increments of light hours near vernal equinox synchronize circannual testicular cycle of tropical spotted munia. Chronobiology International, 21, 553–569. https://doi.org/10.1081/CBI-200025991

[13] COMADRE Animal Matrix Database. (2015). (Version 1.0.0). Germany: Max Planck Institute for Demographic Research. Retrieved from www.comadre-db.org on 9/8/2016

[14] Conklin, J. R., Battley, P. F., & Potter, M. A. (2013). Absolute consistency: Individual versus population variation in annual-cycle schedules of a long-distance migrant bird. PLoS ONE, 8, e54535. https://doi.org/10.1371/journal.pone.0054535

[15] Conklin, J. R., Senner, N. R., Battley, P. F., & Piersma, T. (2017). Extreme migration and the individual quality spectrum. Journal of Avian Biology, 48, 19–36. https://doi.org/10.1111/jav.01316

[16] Cooper, N., Thomas, G. H., Venditti, C., Meade, A., & Freckleton, R. P. (2016). A cautionary note on the use of Ornstein-Uhlenbeck models in macroevolutionary studies. Biological Journal of the Linnean Society, 118, 64–77. https://doi.org/10.1111/bij.12701

[17] Dawson, A. (2008). Control of the annual cycle in birds: Endocrine constraints and plasticity in response to ecological variability. Philosophical Transactions of the Royal Society B, 363, 1621–1633. https://doi.org/10.1098/rstb.2007.0004

[18] Dawson, A. (2015). Annual gonadal cycles in birds: Modeling the effects of photoperiod on seasonal changes in GnRH-1 secretion. Frontiers in Neuroendocrinology, 37, 52–64. https://doi.org/10.1016/j.yfrne.2014.08.004

[19] Dawson, A., King, V. M., Bentley, G. E., & Ball, G. F. (2001). Photoperiodic control of seasonality in birds. Journal of Biological Rhythms, 16, 365–380. https://doi.org/10.1177/074873001129002079

[20] Del Giudice, M., Ellis, B. J., & Shirtcliff, E. A. (2011). The adaptive calibration model of stress responsivity. Neuroscience & Biobehavioral Reviews, 35, 1562–1592. https://doi.org/10.1016/j.neubiorev.2010.11.007

[21] Desholm, M. (2009). Avian sensitivity to mortality: Prioritising migratory bird species for assessment at proposed wind farms. Journal of Environmental Management, 90, 2672–2679. https://doi.org/10.1016/j.jenvman.2009.02.005

[22] Downing, P. A., Cornwallis, C. K., & Griffin, A. S. (2015). Sex, long life and the evolutionary transition to cooperative breeding in birds. Proceedings of the Royal Society B, 282, 20151663. https://doi.org/10.1098/rspb.2015.1663

[23] Drent, R., Both, C., Green, M., Madsen, J., & Piersma, T. (2003). Pay-offs and penalties of competing migratory schedules. Oikos, 103, 274–292. https://doi.org/10.1034/j.1600-0706.2003.12274.x

[24] Drent, R., & Daan, S. (1980). The prudent parent: Energetic adjustments in avian breeding. Ardea, 68, 225–252

[25] Ekman, J., & Askenmo, C. (1986). Reproductive cost, age-specific survival and a comparison of the reproductive strategy in two European tits (genus Parus). Evolution, 40, 159–168

[26] Floessner, T., & Hut, R. A. (2017). Basic principles underlying biological oscillations and their entrainment. In V. Kumar (Ed.), Biological timekeeping: Clocks, rhythms and behaviour (pp. 47–58). New Delhi, India: Springer India. https://doi.org/10.1007/978-81-322-3688-7_3 https://doi.org/10.1007/978-81-322-3688-7

[27] Freeman, S. N., Robinson, R. A., Clark, J. A., Griffin, B. M., & Adams, S. Y. (2007). Changing demography and population decline in the common starling Sturnus vulgaris: A multisite approach to integrated population monitoring. Ibis, 149, 587–596. https://doi.org/10.1111/j.1474-919X.2007.00684.x

[28] Garamszegi, L. Z., & Møller, A. P. (2010). Effects of sample size and intraspecific variation in phylogenetic comparative studies: A meta-analytic review. Biological Reviews, 85, 797–805. https://doi.org/10.1111/j.1469-185X.2010.00126.x

[29] Glazier, D. S. (2015). Is metabolic rate a universal 'pacemaker' for biological processes? Biological Reviews, 90, 377–407. https://doi.org/10.1111/brv.12115

[30] Guillerme, T., & Healy, K. (2014). mulTree: a package for running MCMCglmm analysis on multiple trees. 10.5281/zenodo.12902

[31] Gutiérrez, J. S., Rakhimberdiev, E., Piersma, T., & Thieltges, D. W. (2017). Migration and parasitism: Habitat use, not migration distance, influences helminth species richness in Charadriiform birds. Journal of Biogeography, 44, 1137–1147. https://doi.org/10.1111/jbi.12956

[32] Gwinner, E. (1968). Circannuale Periodik als Grundlage des jahreszeitlichen Funktionswandels bei Zugvögeln: Untersuchungen am Fitis (Phylloscopus trochilus) und am Waldlaubsänger (P. sibilatrix). Journal of Ornithology, 109, 70–95. https://doi.org/10.1007/BF01678108

[33] Gwinner, E. (1971). A comparative study of circannual rhythms in warblers. In M. Menaker (Ed.), Biochronometry (pp. 405–427). Washington, D. C.: National Academy of Sciences

[34] Gwinner, E. (1981). Circannual rhythms: Their dependence on the circadian system. In B. K. Follett & D. E. Follett (Eds.), Biological clocks in seasonal reproductive cycles (pp. 153–169). Bristol: Wright and Sons

[35] Gwinner, E. (1986). Circannual rhythms: Endogenous annual clocks in the organization of seasonal processes. Berlin, Germany: Springer-Verlag. https://doi.org/10.1007/978-3-642-82870-6

[36] Gwinner, E. (2003). Circannual rhythms in birds. Current Opinion in Neurobiology, 13, 770–778. https://doi.org/10.1016/j.conb.2003.10.010

[37] Gwinner, E., & Schwabl-Benzinger, I. (1982). Adaptive temporal programming of molt and migratory disposition in two closely related long-distance migrants, the pied flycatcher (Ficedula hypoleuca) and the collared flycatcher (Ficedula albicollis). In F. Papi (Ed.), Avian Navigation (pp. 75–89). Berlin, Germany: Springer. https://doi.org/10.1007/978-3-642-68616-0

[38] Hadfield, J. D. (2010). MCMC methods for multi-response generalized linear mixed models: The MCMCglmm R package. Journal of Statistical Software, 33, 1–22

[39] Hadfield, J. D., & Nakagawa, S. (2010). General quantitative genetic methods for comparative biology: Phylogenies, taxonomies and multi-trait models for continuous and categorical characters. Journal of Evolutionary Biology, 23, 494–508. https://doi.org/10.1111/j.1420-9101.2009.01915.x

[40] Hahn, T. P. (1998). Reproductive seasonality in an opportunistic breeder, the red crossbill, Loxia curvirostra. Ecology, 79, 2365–2375. https://doi.org/10.1890/0012-9658(1998)079[2365:RSIAOB]2.0.CO;2

[41] Hahn, T. P., & MacDougall-Shackleton, S. A. (2008). Adaptive specialization, conditional plasticity and phylogenetic history in the reproductive cue response systems of birds. Philosophical Transactions of the Royal Society B, 363, 267–286. https://doi.org/10.1098/rstb.2007.2139

[42] Harmon, L. J., Weir, J. T., Brock, C. D., Glor, R. E., & Challenger, W. (2008). GEIGER: Investigating evolutionary radiations. Bioinformatics, 24, 129–131. https://doi.org/10.1093/bioinformatics/btm538

[43] Harts, A. M. F., Kristensen, N. P., & Kokko, H. (2016). Predation can select for later and more synchronous arrival times in migrating species. Oikos, 125, 1528–1538. https://doi.org/10.1111/oik.02973

[44] Harvey, P. H., & Pagel, M. D. (1991). The comparative method in evolutionary biology. Oxford; New York: Oxford University Press

[45] Hau, M., Dominoni, D., Casagrande, S., Buck, C. L., Wagner, G., Hazlerigg, D., … Hut, R. A. (2017). Timing as a sexually selected trait: The right mate at the right moment. Philosophical Transactions of the Royal Society B: Biological Sciences, 372, 20160249. https://doi.org/10.1098/rstb.2016.0249

[46] Hegner, R. E., & Wingfield, J. C. (1986). Behavioral and endocrine correlates of multiple brooding in the semicolonial house sparrow Passer domesticus I. Males. Hormones and Behavior, 20, 294–312. https://doi.org/10.1016/0018-506X(86)90039-5

[47] Helm, B. (2006). Zugunruhe of migratory and non-migratory birds in a circannual context. Journal of Avian Biology, 37, 533–540. https://doi.org/10.1111/j.2006.0908-8857.03947.x

[48] Helm, B., Gwinner, E., & Trost, L. (2005). Flexible seasonal timing and migratory behavior: Results from stonechat breeding programs. Annals of the New York Academy of Sciences, 1046, 216–227. https://doi.org/10.1196/annals.1343.019

[49] Helm, B., & Lincoln, G. A. (2017). Circannual rhythms anticipate the Earth's annual periodicity. In V. Kumar (Ed.), Biological timekeeping: Clocks, rhythms and behaviour (pp. 545–569). New Delhi, India: Springer. https://doi.org/10.1007/978-81-322-3688-7

[50] Helm, B., Piersma, T., & van der Jeugd, H. (2006). Sociable schedules: Interplay between avian seasonal and social behaviour. Animal Behaviour, 72, 245–262. https://doi.org/10.1016/j.anbehav.2005.12.007

[51] Helm, B., Schwabl, I., & Gwinner, E. (2009). Circannual basis of geographically distinct bird schedules. Journal of Experimental Biology, 212, 1259–1269. https://doi.org/10.1242/jeb.025411

[52] Helm, B., & Shavit, A. (2017). Dissecting and reconstructing time and space for replicable biological research. In A. M. Ellison & A. Shavit (Eds.), Stepping in the same river twice: Replication in biological research (pp. 233–249). New Haven, CT: Yale University Press

[53] Helm, B., Visser, M. E., Schwartz, W., Kronfeld-Schor, N., Gerkema, M., Piersma, T., & Bloch, G. (2017). Two sides of a coin: Ecological and chronobiological perspectives of timing in the wild. Philosophical Transactions of the Royal Society B, 372, 20160246. https://doi.org/10.1098/rstb.2016.0246

[54] Holberton, R. L., & Able, K. P. (1992). Persistence of circannual cycles in a migratory bird held in constant dim light. Journal of Comparative Physiology A, 171, 477–481

[55] Huelsenbeck, J. P. (2000). Accommodating phylogenetic uncertainty in evolutionary studies. Science, 288, 2349–2350. https://doi.org/10.1126/science.288.5475.2349

[56] Hut, R. A., Paolucci, S., Dor, R., Kyriacou, C. P., & Daan, S. (2013). Latitudinal clines: An evolutionary view on biological rhythms. Proceedings of the Royal Society B, 280, 20130433. https://doi.org/10.1098/rspb.2013.0433

[57] Jetz, W., Thomas, G. H., Joy, J. B., Hartmann, K., & Mooers, A. O. (2012). The global diversity of birds in space and time. Nature, 491, 444–448. https://doi.org/10.1038/nature11631

[58] Johnston, A., Robinson, R. A., Gargallo, G., Julliard, R., van der Jeugd, H., & Baillie, S. R. (2016). Survival of Afro-Palaearctic passerine migrants in Western Europe and the impacts of seasonal weather variables. Ibis, 158, 465–480. https://doi.org/10.1111/ibi.12366

[59] Jonzén, N., Hedenström, A., & Lundberg, P. (2007). Climate change and the optimal arrival of migratory birds. Proceedings of the Royal Society B, 274, 269–274. https://doi.org/10.1098/rspb.2006.3719

[60] Karagicheva, J., Liebers, M., Rakhimberdiev, E., Hallinger, K. K., Saveliev, A., & Winkler, D. W. (2016). Differences in size between first and replacement clutches match the seasonal decline in single clutches in tree swallows Tachycineta bicolor. Ibis, 158, 607–613. https://doi.org/10.1111/ibi.12368

[61] Karagicheva, J., Rakhimberdiev, E., Dekinga, A., Brugge, M., Koolhaas, A., ten Horn, J., & Piersma, T. (2016). Seasonal time keeping in a long-distance migrating shorebird. Journal of Biological Rhythms, 31, 509–521. https://doi.org/10.1177/0748730416655929

[62] Karagicheva, J., Rakhimberdiev, E., Saveliev, A., & Piersma, T. (2018). Supplementary materials to Karagicheva et al. 2018 Functional Ecology (Version v1.1). Zenodo. https://doi.org/10.5281/zenodo.1250826

[63] Kokko, H. (1999). Competition for early arrival in migratory birds. Journal of Animal Ecology, 68, 940–950. https://doi.org/10.1046/j.1365-2656.1999.00343.x

[64] Kristensen, N. P., Johansson, J., Ripa, J., & Jonzén, N. (2015). Phenology of two interdependent traits in migratory birds in response to climate change. Proceedings of the Royal Society B, 282, 20150288. https://doi.org/10.1098/rspb.2015.0288

[65] Lok, T., Veldhoen, L., Overdijk, O., Tinbergen, J. M., & Piersma, T. (2017). An age-dependent fitness cost of migration? Old trans-Saharan migrating spoonbills breed later than those staying in Europe, and late breeders have lower recruitment. Journal of Animal Ecology, 86, 998–1009. https://doi.org/10.1111/1365-2656.12706

[66] McGraw, J. B., & Caswell, H. (1996). Estimation of individual fitness from life-history data. American Naturalist, 1, 47–64. https://doi.org/10.1086/285839

[67] McKechnie, A. E. (2008). Phenotypic flexibility in basal metabolic rate and the changing view of avian physiological diversity: A review. Journal of Comparative Physiology B, 178, 235–247. https://doi.org/10.1007/s00360-007-0218-8

[68] McNamara, J. M., Welham, R. K., Houston, A. I., Daan, S., & Tinbergen, J. M. (2004). The effects of background mortality on optimal reproduction in a seasonal environment. Theoretical Population Biology, 65, 361–372. https://doi.org/10.1016/j.tpb.2003.10.006

[69] Møller, A. P. (1994). Phenotype-dependent arrival time and its consequences in a migratory bird. Behavioral Ecology and Sociobiology, 35, 115–122. https://doi.org/10.1007/BF00171501

[70] Møller, A. P. (2008). Relative longevity and field metabolic rate in birds. Journal of Evolutionary Biology, 21, 1379–1386. https://doi.org/10.1111/j.1420-9101.2008.01556.x

[71] Møller, A. P. (2009). Basal metabolic rate and risk-taking behaviour in birds: BMR and anti-predator behaviour. Journal of Evolutionary Biology, 22, 2420–2429. https://doi.org/10.1111/j.1420-9101.2009.01850.x

[72] Moreno, J., Gustafsson, L., Carlson, A., & Pärt, T. (1991). The cost of incubation in relation to clutch-size in the collared flycatcher Ficedula albicollis. Ibis, 133, 186–193. https://doi.org/10.1111/j.1474-919X.1991.tb04830.x

[73] Morrison, C. A., Robinson, R. A., Butler, S. J., Clark, J. A., & Gill, J. A. (2016). Demographic drivers of decline and recovery in an Afro-Palaearctic migratory bird population. Proceedings of the Royal Society B: Biological Sciences, 283, 20161387. https://doi.org/10.1098/rspb.2016.1387

[74] Mueller, M., Spaar, R., Schifferli, L., & Jenni, L. (2005). Effects of changes in farming of subalpine meadows on a grassland bird, the whinchat (Saxicola rubetra). Journal of Ornithology, 146, 14–23. https://doi.org/10.1007/s10336-004-0059-0

[75] Nakagawa, S., & Schielzeth, H. (2010). Repeatability for Gaussian and non-Gaussian data: A practical guide for biologists. Biological Reviews, 85, 935–956. https://doi.org/10.1111/j.1469-185X.2010.00141.x

[76] Neill, D. (2013). Life's timekeeper. Ageing Research Reviews, 12, 567–578. https://doi.org/10.1016/j.arr.2013.01.004

[77] Newton, I. (2008). The migration ecology of birds. Amsterdam: Elsevier/Acad. Press

[78] Numata, H., & Helm, B. (Eds.) (2014). Annual, lunar, and tidal clocks: Patterns and mechanisms of nature's enigmatic rhythms. Tokyo; New York: Springer

[79] Öberg, M., Pärt, T., Arlt, D., Laugen, A. T., & Low, M. (2014). Decomposing the seasonal fitness decline. Oecologia, 174, 139–150. https://doi.org/10.1007/s00442-013-2763-z

[80] Orzack, S. H., & Tuljapurkar, S. (2001). Reproductive effort in variable environments, or environmental variation is for the birds. Ecology, 82, 2659–2665. https://doi.org/10.1890/0012-9658(2001)082[2659:REIVEO]2.0.CO;2

[81] Piersma, T. (1987). Hop, skip, or jump? Constraints on migration of arctic waders by feeding, fattening, and flight speed. Limosa, 60, 185–194

[82] Piersma, T., Brugge, M., Spaans, B., & Battley, P. F. (2008). Endogenous circannual rhythmicity in body mass, molt, and plumage of great knots (Calidris tenuirostris). Auk, 125, 140–148. https://doi.org/10.1525/auk.2008.125.1.140

[83] Piersma, T., Cadée, N., & Daan, S. (1995). Seasonality in basal metabolic rate and thermal conductance in a long distance migrant shorebird, the knot (Calidris canutus). Journal of Comparative Physiology, 165, 37–45. https://doi.org/10.1007/BF00264684

[84] Piersma, T., Klaassen, M., Bruggemann, J. H., Blomert, A.-M., Gueye, A., Ntiamoa-Baidu, Y., & van Brederode, N. E. (1990). Seasonal timing of the spring departure of waders from the Banc d'Arguin, Mauritania. Ardea, 78, 123–134

[85] Piersma, T., Lok, T., Chen, Y., Hassell, C. J., Yang, H.-Y., Boyle, A., … Ma, Z. (2016). Simultaneous declines in summer survival of three shorebird species signals a flyway at risk. Journal of Applied Ecology, 53, 479–490. https://doi.org/10.1111/1365-2664.12582 https://doi.org/10.1111/1365-2664.12582

[86] Pohl, H. (1971). Circannuale Periodik beim Bergfinken. Naturwissenschaften, 58(11), 572–573. https://doi.org/10.1007/BF00598733

[87] R Core Team. (2017). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

[88] Rakhimberdiev, E., van den Hout, P. J., Brugge, M., Spaans, B., & Piersma, T. (2015). Seasonal mortality and sequential density dependence in a migratory bird. Journal of Avian Biology, 46, 332–341. https://doi.org/10.1111/jav.00701

[89] Rani, S., & Kumar, V. (2013). Avian circannual systems: Persistence and sex differences. General and Comparative Endocrinology, 190, 61–67. https://doi.org/10.1016/j.ygcen.2013.04.013

[90] Reale, D., Garant, D., Humphries, M. M., Bergeron, P., Careau, V., & Montiglio, P. O. (2010). Personality and the emergence of the pace-of-life syndrome concept at the population level. Philosophical Transactions of the Royal Society B, 365, 4051–4063. https://doi.org/10.1098/rstb.2010.0208

[91] Ricklefs, R. E., & Wikelski, M. (2002). The physiology/life-history nexus. Trends in Ecology & Evolution, 17, 462–468. https://doi.org/10.1016/S0169-5347(02)02578-8

[92] Riede, S. J., van der Vinne, V., & Hut, R. A. (2017). The flexible clock: Predictive and reactive homeostasis, energy balance and the circadian regulation of sleep–wake timing. Journal of Experimental Biology, 220, 738–749. https://doi.org/10.1242/jeb.130757

[93] Roenneberg, T., Daan, S., & Merrow, M. (2003). The art of entrainment. Journal of Biological Rhythms, 18, 183–194. https://doi.org/10.1177/0748730403018003001

[94] Roenneberg, T., Kuehnle, T., Pramstaller, P. P., Ricken, J., Havel, M., Guth, A., & Merrow, M. (2004). A marker for the end of adolescence. Current Biology, 14, R1038–R1039. https://doi.org/10.1016/j.cub.2004.11.039

[95] Sæther, B.-E., & Bakke, Ø. (2000). Avian life history variation and contribution of demographic traits to the population growth rate. Ecology, 81, 642–653. https://doi.org/10.1890/0012-9658(2000)081[0642:ALHVAC]2.0.CO;2

[96] Sanz, J. J. (2001). Latitudinal variation in female local return rate in the philopatric pied flycatcher (Ficedula hypoleuca). Auk, 118, 539. https://doi.org/10.1642/0004-8038(2001)118[0539:LVIFLR]2.0.CO;2

[97] Senar, J., Borras, A., Cabrera, T., & Cabrera, J. (1993). Testing for the relationship between coniferous crop stability and common crossbill residence. Journal of Field Ornithology, 64, 464–469

[98] Silverin, B., Arvidsson, B., & Wingfield, J. (1997). The adrenocortical responses to stress in breeding willow warblers Phylloscopus trochilus in Sweden: Effects of latitude and gender. Functional Ecology, 11, 376–384. https://doi.org/10.1046/j.1365-2435.1997.00097.x

[99] Siriwardena, G. M., Baillie, S. R., & Wilson, J. D. (1998). Variation in the survival rates of some British passerines with respect to their population trends on farmland. Bird Study, 45, 276–292. https://doi.org/10.1080/00063659809461099

[100] Siriwardena, G. M., Baillie, S. R., & Wilson, J. D. (1999). Temporal variation in the annual survival rates of six granivorous birds with contrasting population trends. Ibis, 141, 621–636. https://doi.org/10.1111/j.1474-919X.1999.tb07370.x

[101] Speakman, J. R. (2005). Correlations between physiology and lifespan - two widely ignored problems with comparative studies. Aging Cell, 4, 167–175. https://doi.org/10.1111/j.1474-9726.2005.00162.x

[102] Spiegelhalter, D. J., Best, N. G., Carlin, B. P., & van der Linde, A. (2002). Bayesian measures of model complexity and fit. Journal of the Royal Statistical Society B, 64, 583–639. https://doi.org/10.1111/1467-9868.00353

[103] van Wijk, R. E., Schaub, M., & Bauer, S. (2017). Dependencies in the timing of activities weaken over the annual cycle in a long-distance migratory bird. Behavioral Ecology and Sociobiology, 71, 73. https://doi.org/10.1007/s00265-017-2305-5

[104] Versteegh, M. A., Schwabl, I., Jaquier, S., & Tieleman, B. I. (2012). Do immunological, endocrine and metabolic traits fall on a single pace-of-life axis? Covariation and constraints among physiological systems. Journal of Evolutionary Biology, 25, 1864–1876. https://doi.org/10.1111/j.1420-9101.2012.02574.x

[105] Ward, S. (2004). Singing is not energetically demanding for pied flycatchers, Ficedula hypoleuca. Behavioral Ecology, 15, 477–484. https://doi.org/10.1093/beheco/arh038

[106] Weiser, E. L., Brown, S. C., Lanctot, R. B., Gates, H. R., Abraham, K. F., Bentzen, R. L., … Sandercock, B. K. (2017). Life-history tradeoffs revealed by seasonal declines in reproductive traits of Arctic-breeding shorebirds. Journal of Avian Biology, 49, jav-01531. https://doi.org/10.1111/jav.01531

[107] West-Eberhard, M. J. (2003). Developmental plasticity and evolution. New York, NY: Oxford University Press

[108] Wikelski, M., Martin, L. B., Scheuerlein, A., Robinson, M. T., Robinson, N. D., Helm, B., … Gwinner, E. (2008). Avian circannual clocks: Adaptive significance and possible involvement of energy turnover in their proximate control. Philosophical Transactions of the Royal Society B, 363, 411–423. https://doi.org/10.1098/rstb.2007.2147

[109] Williams, T. D. (2012). Physiological adaptations for breeding in birds. Princeton, NJ: Princeton University Press

[110] Winkler, D. W., Jørgensen, C., Both, C., Houston, A. I., McNamara, J. M., Levey, D. J., … Piersma, T. (2014). Cues, strategies, and outcomes: How migrating vertebrates track environmental change. Movement Ecology, 2, 10. https://doi.org/10.1186/2051-3933-2-10 https://doi.org/10.1186/2051-3933-2-10

[111] Winkler, D. W., Ringelman, K. M., Dunn, P. O., Whittingham, L., Hussell, D. J. T., Clark, R. G., … Ardia, D. R. (2014). Latitudinal variation in clutch size-lay date regressions in Tachycineta swallows: Effects of food supply or demography? Ecography, 37, 670–678. https://doi.org/10.1111/j.1600-0587.2013.00458.x https://doi.org/10.1111/j.1600-0587.2013.00458.x

[112] Young, B. E. (1994). Geographic and seasonal patterns of clutch-size variation in house wrens. The Auk, 111, 545–555

[113] Zuur, A. F., Ieno, E. N., & Smith, G. M. (2007).Analysing ecological data. New York; London: Springer. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=371384 https://doi.org/10.1007/978--387-45972-1

[114] Дольник, В. (1975). Окологодовая цикличность миграционного отложения жира, половой активности и линьки при постоянных фотопериодах у зяблика (Fringilla coelebs). Журн. Общ. Биол, 19746, 543–552